Performance Impairment Following Sleep Restriction – Is Caffeine the Antidote?

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Chapter 1

Introduction

Though a full understanding of sleep and the role it plays has yet to be clearly explained, sleep is required for optimal physiological function. Therefore, it is widely recommended that adults sleep 7 to 9 hours a night, yet much of the population falls short of these guidelines (17, 56). The most recent poll conducted by the National Sleep Foundation found that 40% of respondents acquired less than 6.9 hours of sleep on weekdays (1). Sleep loss can occur through sleep deprivation or sleep restriction. Sleep deprivation is the complete absence of sleep, while sleep restriction is interrupted sleep cycles; these interruptions can occur through delayed sleep, intermittent waking, or early awakening. The importance of sleep is believed to be related to a number of different factors. A commonly accepted theory revolves around energy conservation, as sleep reduces daily metabolic requirements and energy expenditure (14, 42). Also, despite early data to the contrary, recent work clearly indicates that cognitive function is compromised following sleep loss, suggesting the central nervous system is reliant on sleep for optimal functioning (19, 55, 58). Finally, there is compelling evidence that long-lasting immunological memory is built through short adaptive immune responses that occur during sleep (6). When adequate sleep is not achieved, the integrity of these systems is compromised.

Athletes in particular require sufficient sleep, so as to facilitate recovery from the physiological and psychological demands of heavy training and competition (3, 13, 32). Sleep is believed to be critical for athletes due to restoration of the immune system, “paying back” the metabolic cost of the wakeful state, and enhancing memory, learning,

and synaptic plasticity (18, 22). Furthermore, when sleep is curtailed during periods of heavy training, recovery is minimized and the potential for overtraining and maladaptation arises, suggesting the necessity of sleep as a mode of recovery for athletes (4). When sleep loss occurs acutely, restoration of neurocognition and the immune system is inhibited, and could be a factor leading to decreased performance (22). So it seems that sleep loss in athletes in particular has the potential to negatively affect the adaptive physiological and psychological recovery processes. Moreover, athletes are especially susceptible to sleep loss. Many athletes routinely perform consecutive days of high-intensity training bouts, and heavy training has been shown to lead to impaired sleep (25). Further, the psychological stress of multi-day competitions or target competitions can also lead to insufficient sleep. A survey examining sleep habits of 632 athletes before an important competition or game reported that 62.3% of them had experienced poor sleep in the nights before a sports event at least once in the previous twelve months. Some athletes reported lost sleep had no effect on their athletic performance, while others reported decrements in mood, alertness, and athletic performance (16). When their schedules interfere with their sleep, whether involving late bedtime or early arousal, the potential for short- and long-term consequences arises. The deleterious effects of sleep on recovery and physical performance are therefore of interest to both coaches and athletes.

Predictably, complete sleep deprivation has a negative impact on athletic performance varying from strength and anaerobic exercise to prolonged aerobic exercise (9, 34, 35, 40, 46, 49, 51). This could be at least partially related to the well documented changes in perceived exertion and mood states following sleep deprivation (34, 40, 48,

49). Interestingly, the effects that sleep deprivation has on physical performance are conflicting. With the exception of one study, it would seem that sleep deprivation ranging from 30 to 60 hours decreases muscular strength and endurance (53). Significant decreases in muscular strength and endurance were seen through decreased vertical jump, isokinetic knee extension and flexion peak torque, and peak isometric voluntary force (9, 49, 54). Conversely, data indicate that anaerobic performances seem to be unaffected by sleep deprivation (46, 51, 53, 54), with the exception of a recent report that 15-m sprint time was significantly increased when subjects incurred 30 hours of sleep deprivation compared to a full night of sleep (49). While the literature currently agrees that sleep deprivation can substantially (impaired by 3-20%) influence aerobic performance, the mechanisms through which decrements arise have yet to be explained. It would seem that cardiovascular, metabolic and ventilation changes occur as a result of sleep deprivation; however the effects on these parameters are equivocal. In certain conditions, heart rate, oxygen consumption, and ventilation change, while in others these measures stay the same. (34, 36, 40, 46, 53). Discrepancies in protocol may lead to the conflicting evidence; especially in regards to hours of sleep deprivation and exercise protocol and intensity. Studies have examined the effects of sleep deprivation in various amounts greater than 24 hours on performance outcomes of interest which could include time to exhaustion, total work, total distance covered, and maximal exercise intensity (5, 26, 33, 34, 39, 40). So, it appears that sleep deprivation can lead to decreased athletic performance, most notably in prolonged exercise.

In addition to sleep deprivation, some data has been gathered on the effects of acute sleep restriction (i.e. a few hours of lost sleep) on performance. Sleep restriction

seems to have mixed effects on muscular strength. Reilly and Piercy reported that various submaximal and maximal weight lifting tasks were negatively affected by sleep restriction, while others report that handgrip and maximal voluntary contraction of muscles may either decrease or remain unchanged, respectively (21, 44, 45, 50). The effect of sleep restriction on anaerobic performance remains equivocal. While two studies have shown that there is no change in anaerobic performance the morning following sleep restriction, a few have reported decreased mean and peak power in a Wingate test the morning or evening following sleep restriction (2, 21, 38, 51). Interestingly, all of the studies that demonstrated performance decrements utilized early awakening as their form of sleep restriction (2, 21, 52). Similarly to total deprivation, the decrements seen in performance following sleep restriction could be due to effects on RPE and mood states as opposed to physiological mechanisms (21, 39, 52). Less is known about the effects of sleep restriction on aerobic performances. While two studies showed sleep restriction did not affect incremental running and cycling test durations the next day, others have demonstrated that sleep restriction decreases performance in Yo-Yo intermittent and incremental cycling tests (37, 39, 41, 44). Despite conflicting reports, it is clear that sleep restriction in the form of early awakening as opposed to delayed bedtime is more disturbing to afternoon performance in both aerobic and anaerobic exercise (2, 37, 52). It is important to consider that the consequences of sleep restriction might vary due to individual differences such as gender, age, morningness-eveningness classification (e.g. chronotype), amount of sleep required, and sleep latency differences (8, 11, 23, 24). In light of the current literature, it would seem that the effects of sleep restriction have negative consequences on performance.

Importantly, virtually everything that is known about sleep restriction and exercise performance has been derived from subjects that refrained from heavy exercise leading up to the night of sleep restriction. It is logical to expect that sleep loss following demanding exercise may have a more pronounced effect on next-day exercise. In support of this idea, our laboratory recently found that one night of sleep restriction following heavy exercise impairs short-duration cycling performance by approximately 10 percent (12). Because sleep disruption is inevitable and markedly detrimental to performance, it is worthwhile to examine potential strategies to attenuate performance losses.

One candidate strategy is caffeine supplementation; caffeine would seem to have the potential to mitigate the detrimental effects that sleep restriction has on performance through increased neurocognitive function and decreased perceived exertion (7). Extensive research has demonstrated the effectiveness of caffeine as an ergogenic aid for aerobic and anaerobic performance (20, 30, 31, 57). Additionally, our laboratory recently reported that caffeine can enhance 3-km cycling time trial performance, especially early in the day (7, 43). The extent to which caffeine may be able to compensate for the negative effects of sleep loss have not been examined. Considering the efficacy of caffeine as a CNS stimulant, it is plausible that caffeine could attenuate some of neurocognitive factors that might lead to performance impairments (15). Therefore, the purpose of this investigation is to test the hypothesis that caffeine supplementation will attenuate but not eliminate the negative impact that sleep restriction has on next-day performance.

Aims and Hypotheses

Aim 1: To determine if caffeine supplementation attenuates the negative effects that sleep restriction has on 3-km cycling TT performance.

Hypothesis 1: Caffeine supplementation will attenuate but not completely offset the negative effects that sleep restriction has on 3-km cycling TT performance.

Aim 2: To determine if caffeine supplementation attenuates the negative effects that sleep restriction has on muscle work during 30 isokinetic leg extension repetitions.

Hypothesis 2: Caffeine supplementation will attenuate but not completely offset the negative effects that sleep restriction has on muscle work during 30 isokinetic leg extension repetitions.

Aim 3: To determine if caffeine supplementation attenuates the negative effects that sleep restriction has on mood states.

Hypothesis 3: Caffeine supplementation will attenuate but not completely offset the negative effects that sleep restriction has on mood states.

Significance

Sleep plays an important role in psychological and physiological recovery from exercise. Despite a resounding belief from athletes and coaches that sleep is critical to recovery and performance, the role sleep plays in enhancing recovery and promoting performance is still ambiguous. Little has been done to determine the effects of sleep restriction on recovery from heavy exercise and subsequent performance. Sleep restriction appears to negatively affect performance in athletes, especially when sleep restriction occurs in the form of early awakening. This seems to be due to negative impacts on cognitive functioning and mood states, however there may be underlying physiological mechanisms as well. Furthermore, potential strategies to mitigate performance decrements observed following sleep restriction have yet to be tested. Considering the prevalence of sleep loss in athletic populations, it is important to investigate the effects sleep restriction has on recovery from exercise as well as potential ways to ameliorate resulting decrements. The current study has the potential to determine if caffeine supplementation can serve as a method to improve 3km cycling time trial performance following heavy exercise and sleep restriction.

Chapter Two

Methodology

Subjects

Eight to fifteen male and female recreational cyclists from James Madison University will participate in this study. All subjects must perform a minimum of 30 minutes of cycling, one to two days per week, for at least three months prior to the study, and possess a maximum oxygen consumption (VO_{2max}) of ≥ 40 ml/min/kg to qualify for participation. Additionally, participants will score ≤ 7 on the Pittsburg Sleep Quality Index (PSQI) to ensure they have “normal” sleeping habits (10). Participants will be informed of the experimental protocol, risks, and benefits before providing written consent. The study will has been approved by the James Madison Institutional Review Board.

Preliminary Testing

Following height and weight measurements, participants will perform an incremental exercise test to exhaustion on a cycle ergometer (Velotron, Racermate, Inc., Seattle, WA, USA) to determine VO_{2max} and maximum power in watts (Wmax). The participants will warm up for five minutes at a self-selected workload, then begin the test at a workload between 100 and 175 W. The workload will increase every 2 minutes in 50 W increments until volitional fatigue or inability to maintain a cadence of 50 RPM or higher for more than 10 seconds. Breath samples will be collected throughout the test and oxygen consumption will be assessed using the Moxus Modular Metabolic System (AEI Technologies, Pittsburgh, PA, USA). VO_{2max} will be determined by the highest 30-s mean oxygen uptake valu

Experimental Design

Participants will complete a familiarization phase followed by four experimental phases, each separated by five to seven days. The familiarization and experimental phases will consist of two exercise sessions performed on consecutive days (EX1 and EX2). EX1 will consist of baseline performance testing followed by an exercise protocol designed to elicit fatigue. EX2 will be performed the following morning to assess recovery from the exercise protocol, and will only include the performance testing. EX1 and EX2 during the experimental phases will be separated by a night of full sleep (*SLP*+) or a night of restricted sleep (*SLP*-). Sleep will be assigned to each participant in a randomized, crossover design. Participants will be informed of their designated sleep condition following the exercise protocol on EX1 and not before, to prevent reactive behavior changes leading up to the experimental trials.

Familiarization Phase

The familiarization phase will consist of EX1 and EX2 trials (as described below), however sleep, diet, and physical activity will not be controlled for. The participants will complete the trials at predetermined intensities to confirm they can complete the protocol, familiarize themselves with the equipment, and reduce learning-related improvements in performance during the experimental trials.

Experimental Trial 1 (EX1)

Participants will arrive at the Human Performance Lab between 3:00 and 5:00pm, having not consumed alcohol, tobacco, or caffeine for 24 hours. Additionally, they will

arrive having fasted from food for ≥2 hours. Upon arrival, participants will be equipped with a heart rate (HR) monitor (Polar; Lake Success, NY, USA) to wear, and then rested in a reclined position for five minutes. At the cessation of the five minute period, resting HR will be recorded. Participants will then warm up for 20 minutes (10 minutes at 50% Wmax followed by 10 minutes at 60% Wmax) on the aforementioned cycle ergometer, during which metabolic measurements will be assessed, as described below. Following the 20 minute warm-up, participants will begin a computer simulated 3-km cycling time trial. Participants will be encouraged to give a maximal effort before the time trial. Following the time trial, participants will cool down on the bicycle ergometer at a self-selected intensity between 50-100W for 10 minutes. The cool-down intensity will be matched in subsequent trials. Following the cool-down, participants will perform three warm-up and 30 maximal single-leg extensions at 120°/second on an isokinetic dynamometer (Biodex Multi-Joint System - PRO, Biodex Medical Systems, Inc., Shirley, NY, USA). Upon completion of leg extensions, participants will perform a 60-minute sprint interval session, previously used in our laboratory (12). Intervals will alternate between 2 minutes at 95% Wmax and 2 minutes at 50% Wmax. If participants cannot maintain a cadence of ≥50 rpm at 95% Wmax, power output will be reduced by 10% for following sprints.

Experimental Trial 2 (EX2)

Participants will begin EX2 between 7:00am and 9:00am the following morning. Participants will eat a standardized breakfast (detailed below) 2 hours prior to EX2.

Caffeine/placebo capsules will be ingested 1 hour prior to EX2. Resting HR will be recorded after 5 minutes of rest at the start of EX2. Following rest, participants will complete assessments of muscle soreness and mood states (POMS-2, Multi-Health System; North Tonawanda, NY, USA) as detailed below. Participants will then repeat the warm up and time trial protocol from EX1. Participants will cool down on the cycle ergometer at their previously selected intensity. Following the cool-down, participants will perform the same leg-extension protocol from EX1.

Sleep Protocol

Participants will undergo the four experimental trials with 5-7 days between the end of one trial and beginning of another. Participants will be instructed to initiate sleep between 10:00 pm and 12:00 am for all *SLP*+ and *SLP*- trials, replicating the same onset time in all experimental phases. For *SLP*+*,* participants will be instructed to set their wake-up time for 8 hours following sleep onset. After waking up, participants will report to the laboratory for EX2. For *SLP*-, participants will be instructed to set their wake-up time 3.5 hours following sleep onset. After waking up, participants will immediately report to the laboratory whereupon an investigator will accompany them to ensure wakefulness until testing begins. The start time of EX2 will remain constant throughout the experimental phases. The Sleep Cycle smartphone application (Northcube, AB, Göteborg, Sweden) will be used as a “quick sleep check” for the two nights preceding EX1 and the night before EX2. Participants will place the smart phone on their mattress in accordance with manufacturer recommendations and sleep data will be estimated based on motion

detection. In addition to Sleep Cycle, sleep data will be acquired through the use of an Actigraph Accelerometer (Pensacola, FL, USA) worn on the non-dominant wrist.

Caffeine/Placebo Capsules:

A randomly counterbalanced, double blind, placebo controlled design will be utilized to compare the effects of four different treatment conditions. No treatments will be administered during the familiarization trials. During the experimental trials participants will be given 6mg/kg body weight in capsule form containing either rice flour (PLA) or anhydrous caffeine. Capsules will be ingested 1 hour before each EX2 trial. The four treatment conditions will be: *SLP*+ with caffeine capsule (*SLP*+/CAF), 2. *SLP*+ with placebo capsule (*SLP*+/PLA), 3. *SLP*- with caffeine capsule (*SLP*- /CAF), and 4. *SLP*- with placebo capsule (*SLP*- /PLA).

Dependent Measures

3-km Time Trial Performance

3-km time trial performances will be performed on the Velotron cycle ergometer in all EX trials. Time to completion and average power output will be used as the primary performance measures.

Blood Lactate and Glucose

Blood lactate and glucose will be taken at minute 18 of the 20 minute warm-up preceding the 3-km time trial in all EX trials. A finger-stick blood draw will be performed

and blood will be analyzed in a YSI 2300 Stat Plus Analyzer (YSI Incorporated; Yellow Springs, OH, USA).

Muscle Function

Total work and fatigue index will be determined using the Biodex dynamometer mentioned above at 120°/second during all EX trials.

Muscle Soreness

Muscle soreness will be determined through using a visual analog scale from 0-100 mm, with 0mm indicating complete absence of muscle soreness and 100 indicating extreme soreness with noticeable pain and stiffness at all times, as detailed by Saunders et al (47). Soreness will be rated walking up and down a flight of stairs before the start of EX trials.

Oxygen Consumption, Ventilation, & Respiratory Exchange Ratio (VO2, VE, & RER)

VO_2, VE, and RER will be measured using a Moxus metabolic cart during the last 5 minutes of the 20 minute warm-up preceding the 3-km time trial in all EX trials. Values obtained in minutes 17-20 will be averaged and recorded.

Heart Rate & Rate of Perceived Exertion (HR & RPE)

During all EX trials, HR and RPE will be obtained at minute 20 of the 20 minute warm-up preceding the 3-km time trial.

Dietary and Exercise Controls

Participants will record all food and beverage intake for 24 hours before EX1 and continue recording until sleep onset that night. After the first EX phase, copies of food and beverage logs will be provided to the participants to replicate diet habits for the remaining phases. Participants will begin all EX trials after a ≥2 hour fast. Within one hour of completing EX1, participants will consume a meal replacement protein shake. Participants will also be asked to abstain from consuming any other macronutrients within two hours of ending EX1. For all conditions, participants will be instructed to consume a standardized breakfast 2 hours before beginning EX2. The standardized breakfast will consist of orange juice, cereal, and yogurt equaling approximately 400 calories. Participants will also be instructed to record all physical activity for 72 hours prior to EX1 in all phases, and keep physical activity habits for all phases. Additionally, they will be instructed to avoid physical activity the day of EX1 and between EX1 and EX2.

Statistics

Total time to completion and mean power output (Watts) will be used as the performance measures. Data will be log transformed to reduce the effects of non-uniformity. Magnitude-based inferences will be derived about the data using methods previously described by Hopkins and colleagues (29). A previously determined “smallest worthwhile change” in performance will be used as a threshold value for a condition effect (EX1 time trial vs. EX2 time trial). The smallest worthwhile change in performance is defined as 0.3 x the within subject variability of select groups of elite cyclists across repeated time trials (CV = 1.5% for time and estimated 4.5% for power) (27). For all other

variables that will be analyzed, the threshold value for a substantial treatment effect will be defined as 0.2 x within-subject standard deviation, under resting conditions.

Publically available spreadsheets will be used to the likelihood of the true treatment effect (of the population) reaching the substantial change threshold (28). The percent likelihoods will be classified as: <1% almost certainly no chance, 1-5% = very unlikely, 5-25% = unlikely, 25-75% = possible, 75-95% = likely, 95-99% = very likely, >99% almost certain. Clinical inference criteria will be used to classify the effects of all conditions on performance. If the percent chance of the effect reaching the substantial change threshold is <25% and the effect is clear, it will be classified as 'trivial'. If the percent chance of the effect reaching the substantial change threshold for benefit exceeds 25%, but the chance for harm is >0.5%, the effect will be considered "unclear". An exception to the 0.5% chance of harm criterion will be made if the benefit/harm odds ratio is >66, in which the case of the effect will be interpreted as "clear".

Following individual condition analysis, treatment comparisons (*SLP*+/CAF vs *SLP*+/PLA vs *SLP*-/CAF vs *SLP*-/PLA) outcomes will be assessed using the previously mentioned spreadsheets (28). The classification system described above will applied, but mechanistic criteria will be used. If 90% confidence intervals include values that exceed the substantial change threshold for both a positive and negative effect, the effect will be considered 'unclear'.

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